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Sedimentation Impacts on the Growth Rates of the Scleractinian Coral *Acropora formosa* from Fringing Reefs of Tioman Island, Malaysia

(Kesan Pemendapan Terhadap Kadar Tumbesaran Karang Skleraktinia *Acropora formosa* dari Terumbu Pinggir Pulau Tioman, Malaysia)

R. NAKAJIMA*, T. YOSHIDA, Y. FUCHINOUE, T. OKASHITA, T. MAEKAWA, M.R.M. KUSHAIRI, B.H.R. OTHMAN & T. TODA

ABSTRACT

The rates of sedimentation and growth of the branching coral Acropora formosa *at Marine Park, Tulai and Renggis reefs in Tioman Island, Malaysia were surveyed between November 2000 and October 2001. The sedimentation rates were measured using sediment traps and the coral growth rates were measured using digital photography and computer image analysis. The rates of sedimentation at Marine Park (17.3 ± 18.7 mg dry weight cm^{-2} d^{-1}) were 5.0 times higher than the Tulai site and 11.4 times higher than the Renggis site. In contrast, both the linear extension (3.9 ± 0.9 mm month^{-1}) and areal growth rates (3.9 ± 1.7 cm^{2} month^{-1}) of* A. formosa *at Marine Park were significantly less than at Tulai and Renggis. The higher sedimentation and consequent lowered light levels at Marine Park may have resulted in the lower growth of the* Acropora *corals.*

Keywords: Branching coral; linear extension growth; sedimentation; Tioman Island

ABSTRAK

Kadar pemendapan dan tumbesaran karang reranting Acropora formosa *di sekitar terumbu karang kawasan Taman Laut, Pulau Tulai dan Pulau Renggis di persekitaran Pulau Tioman, Malaysia, telah diselidik antara bulan November 2000 dan Oktober 2001. Kadar pemendapan diukur dengan menggunakan perangkap mendapan dan tumbesaran karang dinilai dengan menggunakan imej digital dan perisian komputer. Kadar pemendapan di tapak Taman Laut (17.3 ± 18.7 mg berat kering cm^{-2} h^{-1}) adalah 5.0 kali ganda lebih tinggi berbanding tapak di Pulau Tulai dan 11.4 kali ganda lebih tinggi dari tapak di Pulau Renggis. Sebaliknya, pertumbuhan linear (3.9 ± 0.9 mm bulan^{-1}) dan kadar pertumbuhan permukaan (3.9 ± 1.7 cm^{2} bulan^{-1})* A. farmosa *adalah lebih rendah secara bererti di Taman Laut berbanding Pulau Tulai dan Renggis. Kadar pemendapan dan seterusnya pengurangan penembusan cahaya di Taman Laut mungkin menyebabkan kemunduran kadar pertumbuhan karang* Acropora *di tapak kajian.*

Kata kunci: Kadar pertumbuhan linear; karang reranting; pemendapan; Pulau Tioman

INTRODUCTION

Currently, over 80% of coral reefs in Southeast Asia are threatened by the continued overexploitation of living marine resources and coastal pollution, causing a critical decline in fish resources in this area (Hoegh -Guldberg et al. 2009). Coral reef loss in Southeast Asia is now suspected to lead to a decline in food production by 80%, imperiling 100 million people (Hoegh-Guldberg et al. 2009). In Malaysian waters, nearly all reefs (99%) are threatened by local human activities, with more than 40% under high or very high threat (Burke et al. 2012). Restoration of coral reefs is one of the most urgent issues for sustainable fisheries and marine resources.

Branching corals of the genus *Acropora* have been identified as fast growing species (Wallace & Willis 1994) and are the most dominant and primary builders of the reef framework in Peninsular Malaysia especially in the east coast (Toda et al. 2007). It is therefore important to know the growth rates of the *Acropora* corals and their biological characteristics in relation to the environmental parameters for sustaining and managing coral reefs in Malaysia. Turbidity and sedimentation can have marked effects on coral growth (Meesters et al. 1998). Although there have been many studies of coral growth rates (Crabbe & Smith 2002; Dodge & Vaisnys 1975; Harriott 1998; Hubbard & Scaturo 1985), only a few study the influence of sedimentation on the growth rate of *Acropora* corals (Crabbe & Smith 2002, 2005).

The branching coral, *Acropora formosa*, is widely distributed in the Indo-Pacific region and is very common and frequently dominant in lagoons and fringing reefs (Veron 1993). In the coral reefs of the east coast of Peninsular Malaysia, *A. formosa* is an important dominant reef framework builder (Harborne et al. 2000) and thus this species has a potential importance for coral transplanting in these regions. Here, we surveyed growth rates of *A.*

formosa at three reefs of Tioman Island off the east coast of Peninsular Malaysia using digital photography and computer image analysis, as well as physical measurements of sedimentation. This study was to test the hypothesis that sedimentation influences coral growth of *A. formosa*.

MATERIALS AND METHODS

The research was conducted between March and August in 2001 to capture the growth of corals at three chosen sites of Marine Park (02°49'90"N;104°09'70"E), Renggis (02°48'55"N;104°08'09"E) and Tulai (02°54'71"N;104°06'05"E) at Tioman Island off the east coast of Peninsular Malaysia (Figure 1). The live coral coverage of the study sites in 2001 were 31.1%, 34.6%, and 68.6% at Marine Park, Tulai and Renggis, respectively (Toda et al. 2007). The depth of the sampling sites were 2.0 m, 3.1 m and 6.7 m at Marine Park, Tulai and Renngis, respectively. The average temperature in the water column ranged between 28.2 and 31.0°C (overall mean: 29.1 ± 0.7°C).

Four random allocated transect lines (stainless steel wire), each 10 m long and separated by at least 5 m, were laid on the reef flats at the three sites in March 2001. Both ends of the lines were staked and fixed in the sediments, allowing re-survey of the original transect lines after 6 months (August 2001). Each transect was photographed using a digital camera (Olympus, Camedia, Model C-2040 Zoom) by maintaining a constant vertical distance (about 1 m) between the bottom and the camera. The measuring marks were attached on the line every 0.5 m to calibrate the photographs during image analysis. Growth rates of *A. formosa* was measured by comparing photos taken in March and August. Both linear extension rate (mm $month^{-1}$) and areal growth rate (mm^2 $month^{-1}$) were measured using an image analysis software analySIS® (Olympus). At each site, along the four lines, 5 healthy coral colonies were selected. Increments in linear extension were calculated for each colony using a random selected point of demarcation between separated branches. Increments in areal coverage for each colony were calculated by tracing the coral outline on the digital photographs (Nakajima et al. 2010).

The rates of sedimentation were measured using sediment traps four times; in November 2000, March, June and October 2001 at the three sampling sites. The traps constituted of three plastic jars (one set) with 3:1 height to diameter ratio (diameter, 68 mm; height, 204 mm) following Gardner (1980) and the mouth of the jars lay approximately 40 cm above the bottom sediment surface to reduce sediment re-suspension from the bottom (English et al. 1994; Lee & Mohamed 2011). One set of sediment trap was deployed at each site and kept exposed for 48 h. The sediment and water within the traps were filtered onto GF/F filter (Whatman) and samples were dried at 60°C for 24 h in an oven until constant dry weight and kept in a desiccator. The samples were weighed and the amount of accumulated sediment were calculated. The sedimentation rates are expressed as mg dry weight (DW) cm^{-2} d^{-1}. The weighted samples on the filters were combusted at 500°C for 4 h to determine the proportion (%) of ash (inorganic matter) weight.

Statistical differences in the rates of sedimentation and coral growth were analyzed using one-way ANOVA and then differences among means were analyzed using Tukey-Kramer multiple comparison tests. A difference at $p<0.05$ was considered significant.

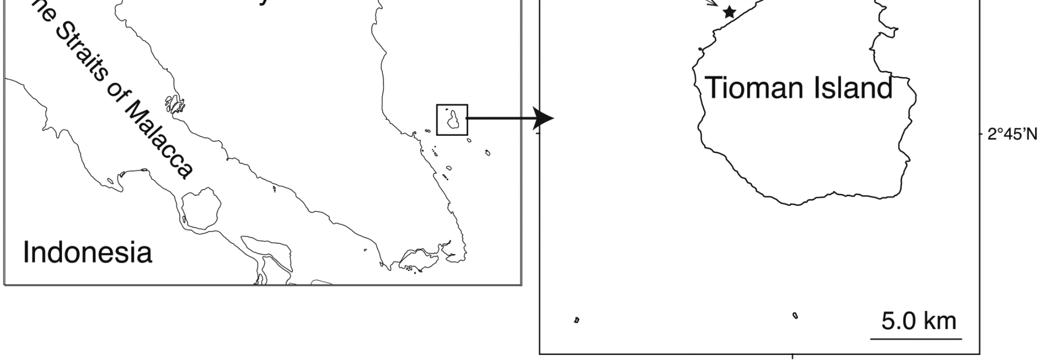

FIGURE 1. Map of the study sites at Tioman Island, Malaysia

Results and Discussion

The rates of sedimentation (mean ± SD) at Marine Park ranged from 4.8 ± 0.9 to 45.1 ± 8.4 mg DW cm^{-2} d^{-1} (overall mean = 17.3 ± 18.7 mg DW cm^{-2} d^{-1}, Table 1) and were 5.0 times higher than the Tulai site (2.5 ± 0.1 – 4.4 ± 0.9 mg DW cm^{-2} d^{-1}, overall mean = 3.4 ± 0.8 mg DW cm^{-2} d^{-1}) and 11.4 times higher than the Renggis site (1.0 ± 0.3 – 1.9 ± 0.2 mg DW cm^{-2} d^{-1}, overall = 1.5 ± 0.4 mg DW cm^{-2} d^{-1}), though there were no statistical differences between sites (one-way ANOVA, p = 0.134) due to the large fluctuation in Marine Park. It is difficult to strictly compare the sedimentation rates in our study with those from previous studies because of high fluctuation in the sedimentation by several factors such as tidal current and wave action. However, the mean sedimentation rates at Tulai (3.4 mg cm^{-2} d^{-1}) and Renggis (1.5 mg cm^{-2} d^{-1}) in the present study are in the range of those reported previously by Lee and Mohamed (2011): 1.1-5.3 mg cm^{-2} d^{-1} at Tulai and 1.0-2.5 mg cm^{-2} d^{-1} at Renggis in April-September 2007. There is currently no comparable study on sedimentation rate at Marine Park.

The percentages of inorganic contents in the sediment samples at Marine Park ranged from 92.6 ± 2.2% to 95.8 ± 1.0% (overall = 94.5 ± 1.7 %, Table 1) and were higher than those at Tulai (65.1 ± 6.1% – 86.4 ± 0.5%, overall = 79.1 ± 9.6%) and Renggis (66.7 ± 1.0% – 81.0 ± 0.9%, overall = 77.3 ± 7.1%) with a statistical significant difference between Marine Park and Renggis (Tukey-Kramer test, p<0.05). The inorganic contents of sediment samples mainly derived from re-suspended sand (carbonate sand particles) in shallow coral reefs (Yahel et al. 2002). The higher inorganic contents of sediment samples at Marine Park suggest that re-suspension of the bottom sediment may be higher at Marine Park. At shallower depths, wave energy becomes high and causes re-suspended sediment to settle in sediment trap (Lee & Mohamed 2011). Although the three study sites are close enough to experience similar wave current, the depth at Marine Park (2.0 m) is shallower than at Tulai (3.1 m) and Renggis (6.7m), suggesting the bottom sediments at Marine Park are more likely to re-suspend by the wave action. Moreover, the areal proportion of inorganic sediment (mainly of sand) to the sea bottom was higher at Marine Park (42.0%) than Tulai (12.2%) and Renggis (14.4%, Toda et al. 2007), which also contributes to the higher re-suspension of bottom sand sediment, which may be the reasons for the higher sedimentation rate and higher fluctuation at Marine Park.

The linear extension rates (mean ± SD) of *A. formosa* at Marine Park were significantly (Tukey-Kramer test, p<0.01) less at Marine Park (3.9 ± 0.9 mm $month^{-1}$) than Tulai (6.0 ± 1.4 mm $month^{-1}$) and Renggis (7.2 ± 0.9 mm $month^{-1}$) (Figure 2(a)). The areal growth rates (cm^2 $month^{-1}$) were also significantly (Tukey-Kramer test, p<0.05) lower at Marine Park (3.9 ± 1.7 cm^2 $month^{-1}$) than the other sites (9.7 ± 3.7 cm^2 $month^{-1}$ at Tulai and 10.6 ± 3.5 cm^2 $month^{-1}$ at Renggis, Figure 2(b)). These results are consistent with the hypothesis that high sedimentation levels would limit coral growth (Crabbe & Smith 2002) as the sedimentation rates were higher at Marine Park.

Although several factors can affect the growth of corals such as light, temperature, nutrients and salinity (Harriot 1998; Tanaka 2012; Yamazato 1991), sedimentation is also an important factor controlling coral growth and thus reef development (Hubbard 1986; Riegl 1995; Rogers 1990). Sedimentation can interfere with corals directly by influencing growth rates (Hubbard & Scaturo 1985), because corals and their symbiotic zooxanthellae depend on light for rapid deposition of calcium carbonate (Chalker 1981), high turbidity and sedimentation and consequent lowered light levels can reduce coral growth rates. Growth of corals may also decrease by the diversion of energy to the removal of sediment particles from their surface (Dodge & Lang 1983). Although we did not measure light intensity during the study, it is likely that the higher sedimentation and consequent possible lowered light levels as well as sediment deposition on corals at Marine Park could have resulted in the lower growth of the *Acropora* corals.

We compared the growth of *A. formosa* corals under different sedimentation conditions in this study. Although the variation in the data was large and the available data are limited, areas with higher sedimentation rates corresponded with lower linear extension and areal growth rates. It would be important to choose the site which has lower sedimentation rate for coral transplanting for restoration of coral reefs.

TABLE 1. Sedimentation rates (mg DW cm^{-2} d^{-1}) and inorganic matter content (%) of three reef sites in Tioman Island, Malaysia. Values are given as means ± SD. DW, dry weight. ND, no data

Date	Marine Park		Tulai		Renggis	
	Sedimentation (mg DW cm^{-2} d^{-1})	% inorganic (%)	Sedimentation (mg DW cm^{-2} d^{-1})	% inorganic (%)	Sedimentation (mg DW cm^{-2} d^{-1})	% inorganic (%)
November 2000	4.8 ± 0.9	95.8 ± 1.0	3.8 ± 0.5	86.4 ± 0.5	1.9 ± 0.2	81.0 ± 0.8
March 2001	45.1 ± 8.4	95.1 ± 0.4	2.5 ± 0.1	65.1 ± 6.1	1.6 ± 0.2	80.5 ± 0.4
June 2001	10.0 ± 2.3	ND	3.1 ± 0.9	84.3 ± 1.1	1.6 ± 0.6	66.7 ± 1.0
October 2001	9.1 ± 0.3	92.6 ± 2.2	4.4 ± 0.9	80.7 ± 2.1	1.0 ± 0.3	81.0 ± 0.9
Overall	17.3 ± 18.7	94.5 ± 1.7	3.4 ± 0.8	79.1 ± 9.6	1.5 ± 0.4	77.3 ± 7.1

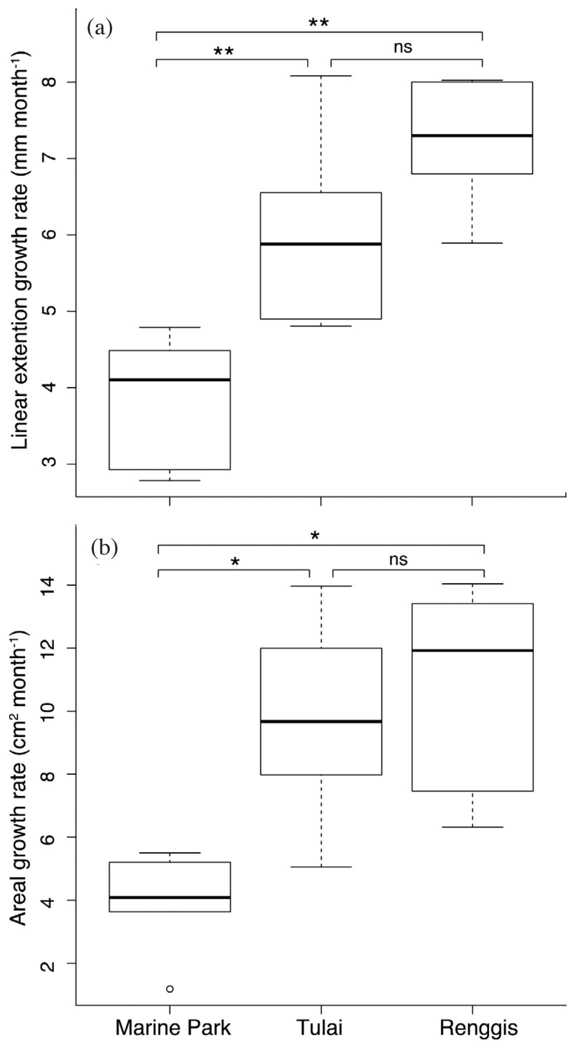

FIGURE 2. Box plot of (a) linear extension growth rate (mm month^{-1}) and (b) areal growth rate (cm^2 month^{-1}) of *Acropora formosa* at three sites in Tioman Island. *p* values pertain to the mean differences between the sites (**: $p<0.01$; *: $p<0.05$; ns: not significant)

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R. Nakajima*
Marine Biodiversity Research Program
Institute of Biogiosciences
Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
Yokosuka, 237-0061 Kanagawa
Japan

T. Yoshida & B.H.R. Othman
Marine Ecosystem Research Centre
Faculty of Science and Technology
Universiti Kebangsaan Malaysia
43600 Bangi, Selangor D.E.
Malaysia

Y. Fuchinoue, T. Okashita, T. Maekawa & T. Toda
Department of Environmental Engineering for Symbiosis
Faculty of Engineering
Soka University, Hachioji
192-8577 Tokyo
Japan

M.R.M. Kushairi
Faculty of Science & Environmental Technology
Universiti Industri Selangor, Batang Berjuntai
45000 Kuala Selangor
Malaysia

*Corresponding author; email: nakajimar@jamstec.go.jp

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